

# SuperKEKB/Belle II upgrades

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- Review of SuperKEKB/Belle II
- Current Performance (Where we are so far).
- Program for the next ten years to reach  $\text{Int(Ldt)} = 50\text{ab}^{-1}$  at the  $\Upsilon(4S)$ , which will enable major breakthroughs in NP searches. See the 689 page Belle II physics book,  
<https://arxiv.org/abs/1808.10567>
- Electron beam Polarization upgrade
- Linac energy upgrade to reach the  $\Lambda_b$ -pair threshold (11.24 GeV)

*We welcome international collaboration on SuperKEKB and its upgrades.* Synergies with other accelerator projects can be discussed further (e.g.FCC-ee, LHC, EIC etc) within the Snowmass process. N.B. the crab-waist, implemented at SuperKEKB in 2020, was one of the concrete results of such synergistic discussions in recent years.

SuperKEKB, the first new collider in particle physics since the LHC in 2008 (electron-positron ( $e^+e^-$ ) rather than proton-proton (pp)). The beam energies are 7 GeV  $e^-$  on 4 GeV  $e^+$  with a boost ( $\beta\gamma\sim 0.28$ ).

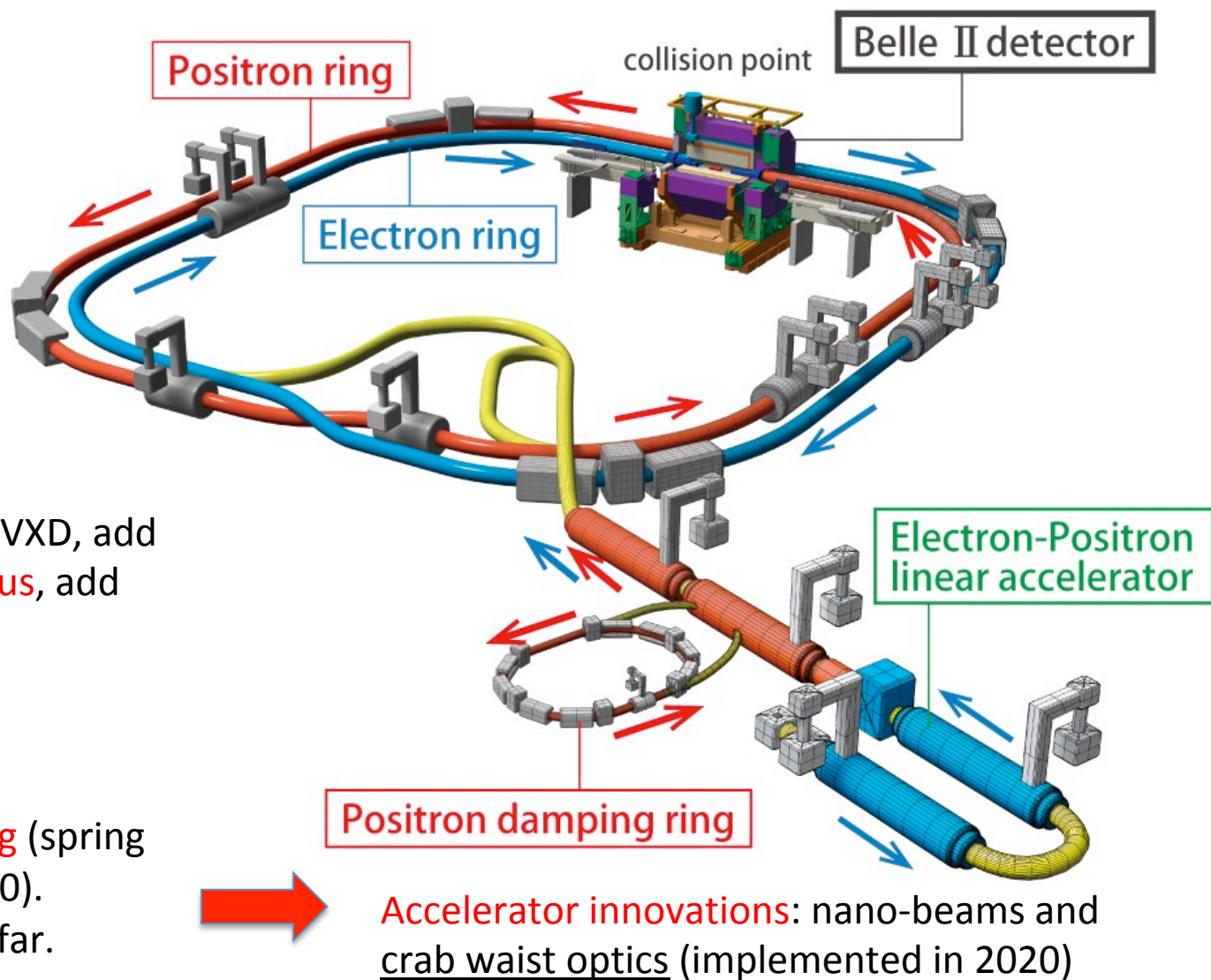


Phase 1:  
Background, Optics  
Commissioning  
Feb-June 2016.

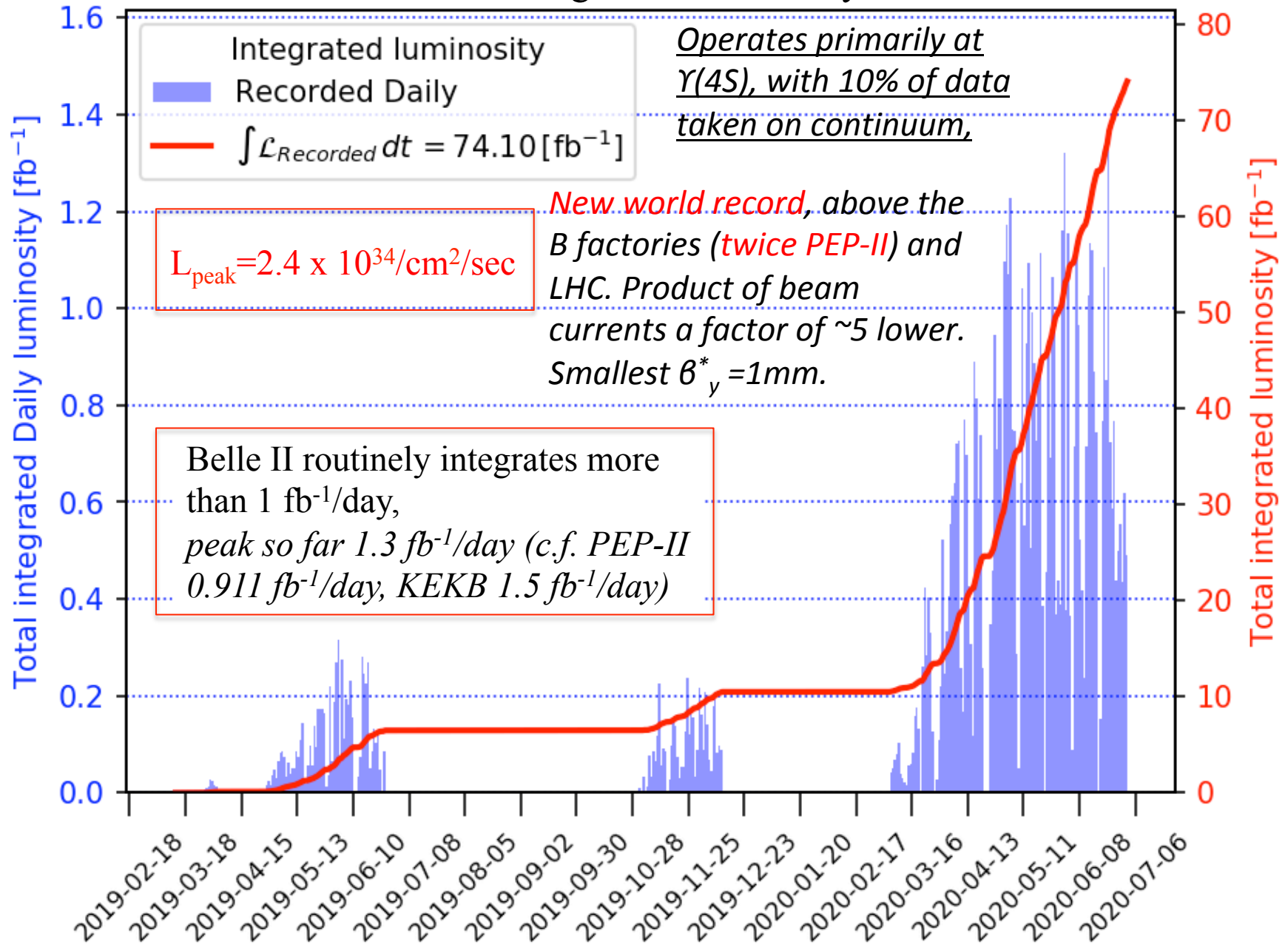
Brand new  
3 km positron ring.

Phase 2: Pilot run without VXD, add  
Superconducting Final Focus, add  
positron damping ring,  
First Collisions ( $0.5 \text{ fb}^{-1}$ ).  
April 27-July 17, 2018

Phase 3: → Physics running (spring  
2019, fall 2019, spring 2020).  
Have integrated  $74 \text{ fb}^{-1}$  so far.

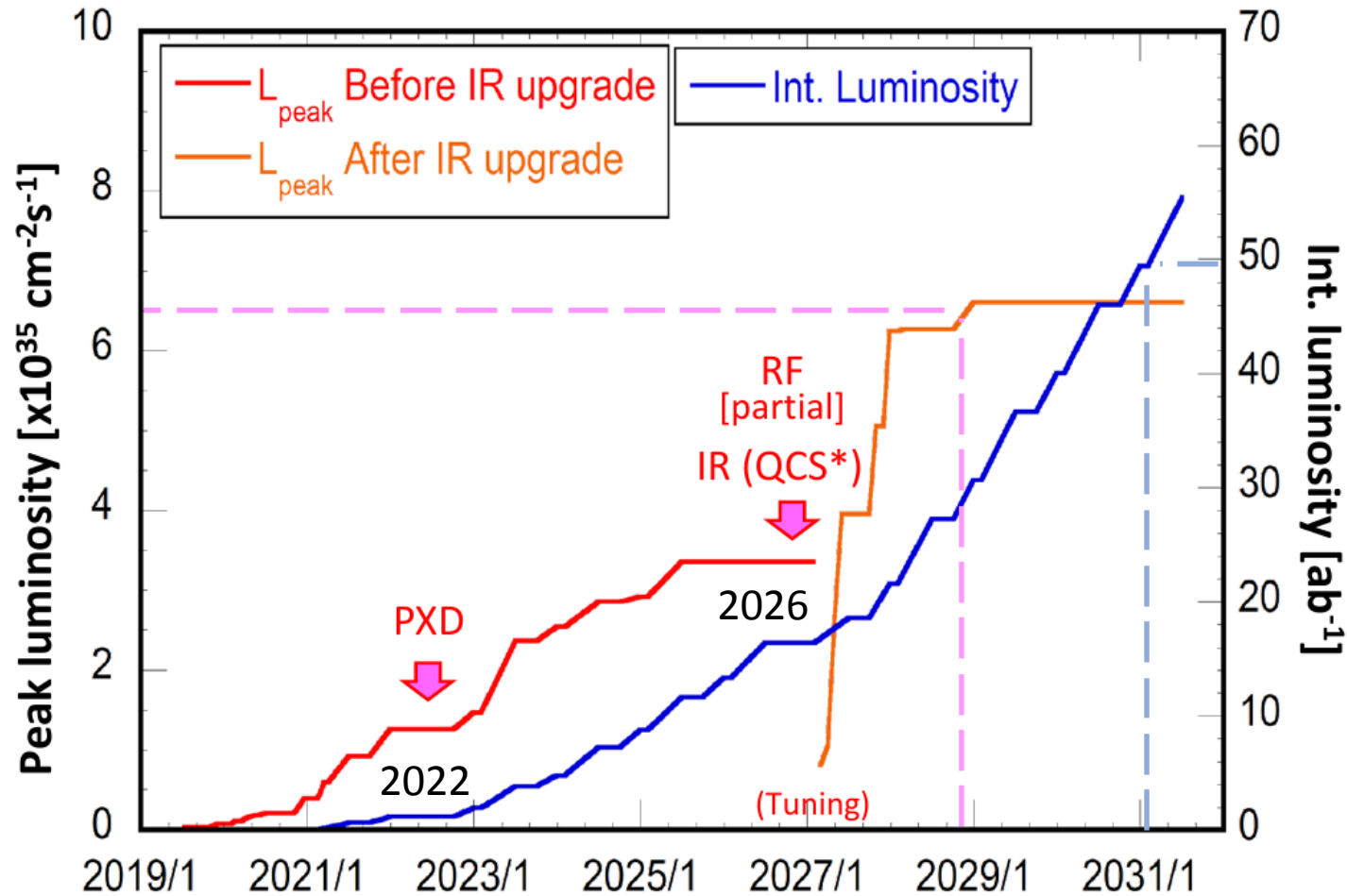


# Belle II Integrated Luminosity



Also see <https://cerncourier.com/a/kek-reclaims-luminosity-record/>

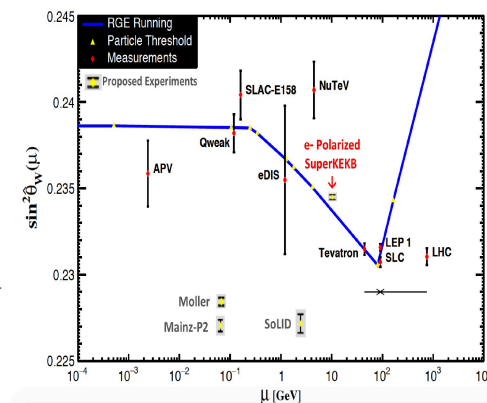
# Updated plan for SuperKEKB submitted to the MEXT Roadmap Committee



Four steps: *Intermediate luminosity* ( $1\text{-}2 \times 10^{35} \text{ /cm}^2\text{/sec}$ ,  $5\text{ab}^{-1}$ );  
High Luminosity ( $6.5 \times 10^{35}\text{/cm}^2\text{/sec}$ ,  $50 \text{ ab}^{-1}$ ) with a detector upgrade  
Polarization Upgrade, Advanced R&D (See talk by M. Roney)  
Ultra high luminosity ( $4 \times 10^{36}\text{/cm}^2\text{/sec}$ ,  $250 \text{ ab}^{-1}$ ), R&D Project

# Upgrading SuperKEKB with Polarized e- Beam

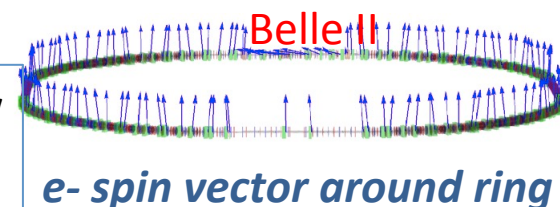
Physics case: precision  $\sin^2 \theta_W$  measurements from  $b, c, e, \mu$  &  $\tau$ , probing its running and universality (see M. Roney's talk in this session). Planning 70% polarization with 80% polarized source (cf 75% @SLD)



## NEW HARDWARE FOR POLARIZATION UPGRADE:

- **Low emittance polarized Source:** electron helicity can be flipped bunch-to-bunch by controlling circular polarization of source laser illuminating a GaAs photocathode (à la SLC). Inject vertically polarized electrons into the 7 GeV e-Ring, needs low enough emittance source to be able to inject.
- **Spin rotators:** Rotate spin to longitudinal before Interaction Point (IP) in Belle II, and then back to vertical after IP using solenoidal and dipole fields
- **Compton polarimeter:** monitors longitudinal polarization with <1% absolute precision, higher for relative measurements (arXiv:1009.6178) - provides real time polarimetry. → Use tau decays from  $e^+e^- \rightarrow \tau^+ \tau^-$  measured in Belle II to provide high precision absolute average polarization at IP.

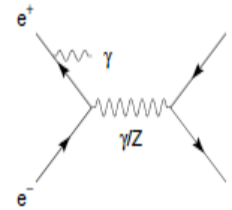
Planning for implementation ~2026 in mid-decade upgrade window for new final focus; This upgrade proposal to be included in KEK Roadmap for MEXT to be submitted 2021



# Backup Slides

# Precision Neutral Current Electroweak Program with SuperKEKB Upgraded to have Polarized e<sup>-</sup> Beams

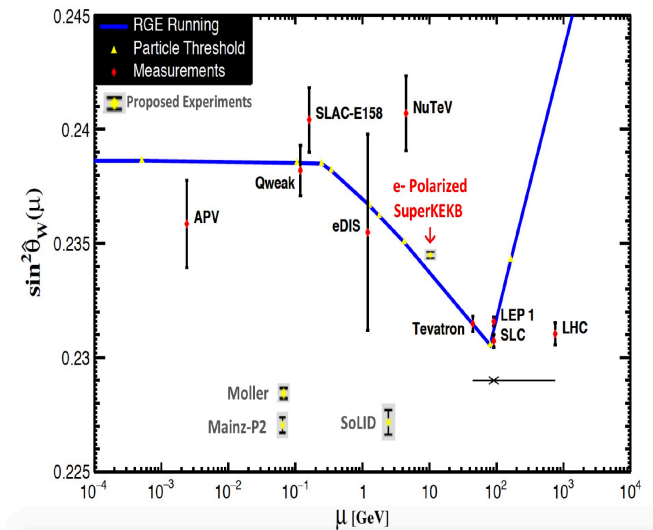
At 10.58 GeV, e<sup>-</sup> polarization enables A<sub>LR</sub> measurements **sensitive to Z-γ interference** 20ab<sup>-1</sup> and 70% polarization at IP gives:



$$A_{LR} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = \frac{4}{\sqrt{2}} \left( \frac{G_F s}{4\pi\alpha Q_f} \right) \left( g_{A8V}^e g_V^f \right) (Pol)$$

$$\propto T_3^f - 2Q_f \sin^2 \theta_W$$

- **World's most precise  $\sin^2 \theta_W$  ( $\sigma(\sin^2 \theta_W) \sim 0.00016$ ) and probe of its running**
- Unprecedented and clean NC universality studies for e,  $\mu$ ,  $\tau$ , b and c since beam polarization error cancels (e.g. < 0.05% relative error for b-to-c, cf 4% now)
- **$\sin^2 \theta_W$  with light quarks at 10.58GeV**
- Sensitivity to Z' > TeV scale and dark sector parity-violating Z' <sub>D</sub> below M<sub>Z</sub>



More information at  
[arxiv.org/abs/1907.03503](https://arxiv.org/abs/1907.03503)

Beyond EW e- polarization at SuperKEKB:

- enables more precise  $\tau$  EDM and  $(g-2)_\tau$
- reduces backgrounds in  $\tau \rightarrow \mu \gamma$  and  $\tau \rightarrow e \gamma$  searches and distinguishes Left & Right handed New Physics currents
- can be used to probe dynamical mass generation in QCD via polarized L

**To be proposed for implementation ~2026 with upgrade proposal to be included in KEK Roadmap for MEXT to be submitted in 2021**



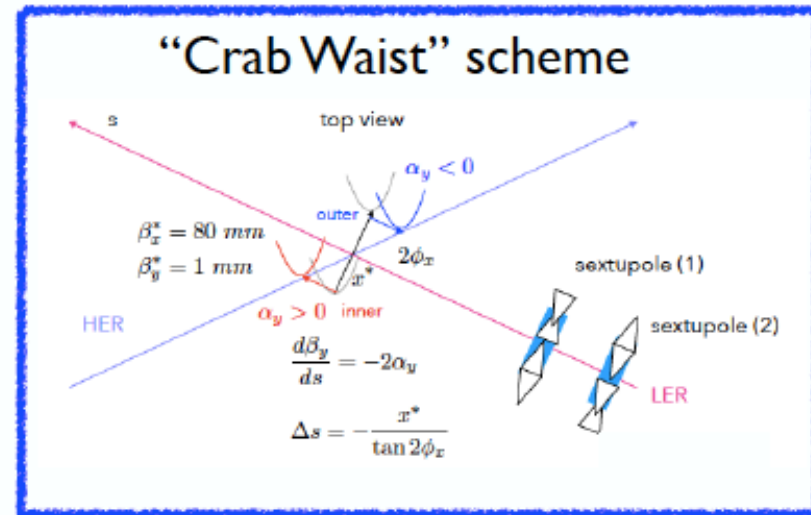
# SuperKEKB Luminosity in 2020a, b

- Max current = 770mA(LER) / 660mA(HER)
- $L_{\text{peak}} = 2.4 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}$
- Int. luminosity/day = 1.346 fb<sup>-1</sup>/1.498 fb<sup>-1</sup>

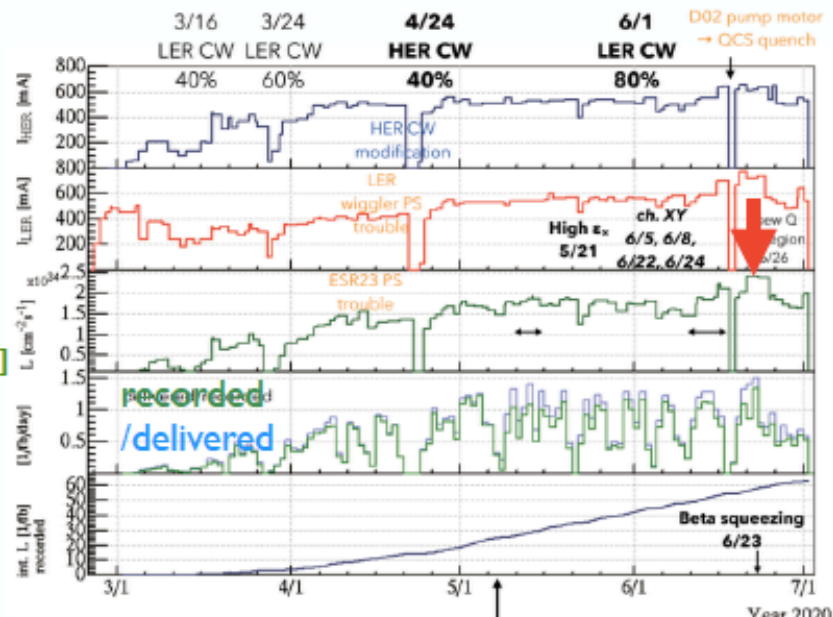
## KEKB record

- $L_{\text{peak}} = 2.11 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}$
- $L_{\text{day}}^{\text{max}} = 1.48 \text{fb}^{-1}$  (2009.6.14)

- LER:  $\beta_x^*/\beta_y^* = 80\text{mm}/1\text{mm} \rightarrow 60\text{mm}/0.8\text{mm}$
- HER:  $\beta_x^*/\beta_y^* = 60\text{mm}/1\text{mm} \rightarrow 60\text{mm}/0.8\text{mm}$



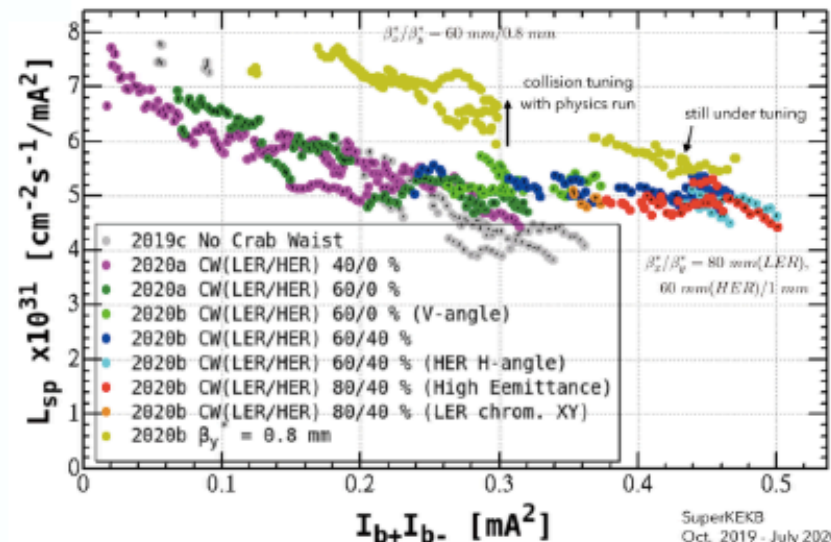
## Operation history in 2020a,b



## Specific luminosity

$$L_{\text{sp}} = \frac{L}{I_{b+} I_{b-} n_b} \propto \frac{1}{\sigma_{x,eff}^* \sigma_y^*}$$

$\rho_y^* = 1 \text{ mm and } 0.8 \text{ mm}$





In this Letter of Interest (LOI), we describe the planned upgrades of the SuperKEKB accelerator at KEK, and additionally list all the Snowmass LOIs submitted on behalf of the Belle II Collaboration and U.S. Belle II. The upgrades will allow increasingly sensitive searches for possible New Physics (NP) that are both complementary to and competitive with the LHC and other experiments. The physics program and potential NP reach of Belle II are comprehensively described in the Belle II Physics Book,<sup>1</sup> which was the result of a collaboration between Belle II members and theorists which remains active and ongoing through the Belle II Theory Interface Platform (B2TIP). We continue to welcome new contributions from the theoretical and experimental community that may help expand the scope and reach of Belle II physics.

We have submitted additional Snowmass 2021 LOIs in several thematic areas to accompany this one. Each briefly summarizes the future prospects for the Belle II physics program which are expected to result from both the current configuration of the experiment as well as from planned upgrades:

- (AF05) Accelerators for rare processes and precision measurements
  - Belle II/SuperKEKB Upgrades & Overview
- (RF01) Weak Decays of b and c quarks (2 LOIs)
  - Belle II/SuperKEKB capabilities for B physics
  - Charm Physics at Belle II
- (RF06) Dark Sector at Low Energies
  - Dark sector studies at Belle II
- (RF02) Strange & Light Quarks, (RF05) Charged Lepton Flavor Violation (electrons, muons and taus), (RF06) Dark Sector at Low Energies, (AF05) Accelerators for rare processes and precision measurements, (EF04) EW Physics: EW Precision Physics and constraining new physics, (EF10) BSM: Dark Matter at colliders
  - Tau Physics and Precision Electroweak Physics with Polarized Beams at SuperKEKB/Belle II
- (RF07) Hadron Spectroscopy
  - Belle II/SuperKEKB capabilities for hadron spectroscopy
- (EF05) QCD and strong interactions: Precision QCD, (EF06) QCD and strong interactions: Hadronic structure and forward QCD, (RF03) Fundamental Physics in Small Experiments
  - QCD and Hadronization Studies at Belle II
- (CF03) Machine Learning, (CF5) End user analysis, (CF7) Reinterpretation and long-term preservation of data and code
  - Computing, Software, and Analysis capabilities for the Belle II Experiment

- (IF02) Photon Detectors, (IF03) Solid State Detectors & Tracking, (IF04) Trigger & DAQ, (IF05) Micro Pattern Gas Detectors, (IF06) Calorimetry, (IF07) Electronics/ASICS

– Belle II Detector Upgrades

Belle II is an international collaboration of  $\sim 1000$  members at more than 100 institutions in 26 countries; U.S. Belle II accounts for  $\sim 120$  members at 18 U.S. universities and national labs. The primary systems responsibilities of U.S. Belle II include the iTOP (imaging Time Of Propagation) subdetector used for charged particle identification, the KLM (KLong Muon) subdetector, background commissioning detectors and computing operations.

SuperKEKB/Belle II was commissioned with colliding beams in 2018. The first physics run after installation of the vertex detector was in Spring 2019, followed by runs in Fall 2019 and Spring 2020. In spring 2020, SuperKEKB surpassed the highest recorded instantaneous luminosities of the B factories and LHC with a peak luminosity of  $2.4 \times 10^{34} \text{cm}^{-2} \text{sec}^{-1}$ . Belle II datataking has thus far operated smoothly with acceptable backgrounds and has routinely integrated  $\sim 1 \text{fb}^{-1}$  of data per day in Spring 2020. As of June 2020, Belle II has integrated  $74 \text{fb}^{-1}$  of physics data at and slightly below the  $T(4S)$  resonance.

SuperKEKB is expected to be able to reach instantaneous luminosities of  $\sim (1\text{-}2) \times 10^{35} \text{cm}^{-2} \text{sec}^{-1}$  with the existing accelerator complex. However, in order to reach peak luminosities up to  $6.5 \times 10^{35} \text{cm}^{-2} \text{sec}^{-1}$ , an upgrade of the interaction region and the QCS superconducting final focus will be required. To handle the increased data rates which will result from these upgrades, a DAQ upgrade is currently under way. Also accompanying the machine upgrades are several planned detector upgrades, including a new pixel vertex detector and upgrades of the particle identification systems to optimally perform in the presence of the increased backgrounds, occupancies and radiation doses expected with the luminosity improvements. These detector upgrades are more fully described in several Snowmass LOI(s) submitted to the Instrumentation Frontier.

Belle II/SuperKEKB operations and upgrades over the next  $\sim 1\text{-}2$  decades are expected to factorize into several distinct epochs:

1. Intermediate luminosity,  $\mathcal{L}_{\text{peak}} \sim 1 \times 10^{35} \text{cm}^{-2} \text{sec}^{-1}$ ,  $\mathcal{L}_{\text{int}} \sim 5 \text{ab}^{-1}$ : The required upgrades of detector and machine for the intermediate luminosity epoch have been approved and baselined. They will be realized over the next few years.
2. High luminosity,  $\mathcal{L}_{\text{peak}} \sim 6.5 \times 10^{35} \text{cm}^{-2} \text{sec}^{-1}$ ,  $\mathcal{L}_{\text{int}} \sim 50 \text{ab}^{-1}$ : The high-lumi upgrade has been approved and incorporated into the SuperKEKB project. The technical design is currently under review.
3. Electron beam polarization at high luminosity: Currently in R&D, this upgrade would require modest additional hardware investments. With a goal of  $\sim 70\%$  electron beam polarization, this upgrade would open unexplored NP discovery windows through a new and unique program of electroweak measurements of unprecedented precision involving beauty, charm and all three generations of charged leptons.
4. Ultra-high luminosity,  $\mathcal{L}_{\text{peak}} \sim 2.5 \times 10^{36} \text{cm}^{-2} \text{sec}^{-1}$ ,  $\mathcal{L}_{\text{int}} \sim 200 - 250 \text{ab}^{-1}$ : Currently in R&D.

# *Snowmass 2021 Letter of Interest:* Belle II/SuperKEKB Upgrades & Overview

on behalf of the U.S. Belle II Collaboration

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